Indian J. Phys. **70B** (2), 141–146 (1996)

NOTE

IJP B
— an international journal

Integral coherent scattering cross sections of 205.2 and 298.6 keV gamma rays in Al, Cu, Sn and Pb at small angles

K S Puttaswamy and Marigowda*
Department of Physics, Manasagangotri, Mysore-570 006, India

Received 31 May 1995, accepted 19 January 1996

Abstract : The integral Rayleigh scattering cross sections of 205.2 and 298.6 keV gamma rays in Al, Cu, Sn and Pb have been determined by forward angle cone method at angles < 6° and are compared with the theoretical values computed using the non-relativistic form factor (NRFF) values of Hubbell *et al*, relativistic form factor (RFF) values of Hubbell and Overbo and modified form factor (MFF) values of Schaupp *et al*. The present experimental results are in good agreement with each of the values within the experimental errors. However for medium- and high-Z elements, the results are consistently closer to the MFF values as the scattering angle increases. RFF values are found to be consistently larger for high-Z elements.

Keywords : Interaction of γ-rays with matter, Rayleigh scattering, form factors

PACS No. : 32.80.Cy

The advance in experimental technique due to high resolution semiconductor detectors and increasing capability of numerical computations have sustained the long standing interest in the study of Rayleigh scattering of X-rays and γ-rays by atoms. Numerical second order S-matrix calculations with more and more realistic wave functions and realistic treatment of Rayleigh scattering have shown that modified relativistic form factor approximation can reproduce the exact forward-angle high-energy limit Rayleigh scattering amplitudes for all shells except close to the electron binding energies [1–5]. Since, even semiconductor detectors cannot resolve elastic and inelastic components [6] below 3°, more efficient NaI(Tl) detectors are preferred in an alternative method [7] at forward angle Rayleigh scattering studies. This alternative method which determines forward-angle integral Rayleigh scattering cross sections (IRSCS) from 0 to θ^0 is free from most of the approximations used in the conventional shadow cone method. It is simple, straight-forward

*Maharani's Science College, Mysore-570 005, India

and just involves the measurement of the scattered photon intensity superposed as a small addition to the direct transmitted beam intensity. There is no need to determine the absolute source strength and the geometrical factor as required by the shadow-cone method which introduces large uncertainties in the measured values. The only approximation which is inevitable in any method at forward-angle Rayleigh scattering studies is the subtraction of unresolved, relatively small but considered to be accurately known theoretical Compton Scattering cross sections from the measured total scattering cross sections. The measured IRSCS [7,8] at 661.6, 279 and 145 keV showed fairly good agreement with each one of the non-relativistic form factor values (NRFF) [9], relativistic form factor (RFF) [10] values and modified form factor values (MFF) [11] within the experimental errors. However, for medium- and high-Z elements, the MFF values were found to be closer with experimental values as the scattering angle increases. In this experiment, measurements were extended to 205.2 and 298.6 keV γ-rays of TB-160 (73 *d* halflife), obtained in the form of steel-welded radiographic capsule from Isotope Division, BARC, Bombay, India. The results are compared with NRFF, RFF and MFF values and found to have similar agreement as earlier.

The experimental set up and the principle of the method used in the present study have been described in detail elsewhere [7]. However for the sake of clarity and self explanation, it is briefly described as follows. In this method, the set-up used in the total attenuation cross section measurement has been slightly modified so that when the scatterer is placed at one position, only the direct transmitted beam intensity is recorded by the detector by eliminating all the possible scattered photons using lead collimators having very narrow collimating holes of diameter 0.4 cm in order to obtain sharp beam of γ-rays. When the scatterer is placed at another position, the photons scattered within a cone of half-angle θ are recorded in addition to the direct transmitted beam intensity. The second position was varied between the last collimator and the detector in order to vary the scattering angle θ from 2° to 6°. The outer edge of the detector was shielded in order to avoid the edge effect [7].

The γ spectra of Tb-160 were recorded by ORTEC 7150 MCA and the time for each spectrum was adjusted to get at least 10^5 counts in the photopeak region in order to reduce the statistical error. The spectrum was fitted with a smoothed curve. The area under the photopeak (background subtracted) was noted and taken to be the intensities of γ-rays. The intensities were corrected for short halflife of Tb-160. The experiment was repeated atleast five times for each of the elements and for each positions. The integral scattering cross sections and the errors were calculated from the intensities as described in our earlier papers. The errors quoted corresponds to statistical errors, the errors due to scattering angle consideration and the errors due to the measurement of scatterer thickness.

The integral scattering cross sections thus measured, comprises both Rayleigh scattering and Compton (incoherent) scattering cross sections because of nearly the same energy at forward angle. Since, the Compton scattering is quite small at forward angle and accurately described with good accuracy by the non-relativistic HF-incoherent scattering function approximation at forward angles, the IRSCS are obtained by subtracting relatively small and accurately calculated integral Compton scattering cross sections [6,9]. The IRSCS of 205.2 and 298.6 keV photons of Al, Cu, Sn and Pb thus obtained are given in the Tables 1 and 2 respectively along with the theoretical values of NRFF, RFF and MFF.

Table 1. Integral Rayleigh scattering cross sections of 205.2 keV gamma rays (b/atom).

Element (Z)	Angle (deg)	$(\Delta\sigma_{sca})$ Theory			$(\Delta\sigma_{sca})$ Expt.
		NRFF	RFF	MFF	
	1.81	0.024	0.024	0.024	0.030 ± 0.005
Al (13)	2.65	0.041	0.041	0.040	0.042 ± 0.005
	3.41	0.054	0.054	0.054	0.051 ± 0.005
	1.81	0.149	0.149	0.147	0.14 ± 0.02
	2.65	0.253	0.253	0.248	0.23 ± 0.02
Cu (29)	3.41	0.335	0.335	0.329	0.33 ± 0.02
	4.76	0.451	0.451	0.443	0.45 ± 0.02
	5.97	0.529	0.530	0.521	0.52 ± 0.02
	1.81	0.438	0.440	0.433	0.42 ± 0.08
	2.65	0.758	0.760	0.747	0.75 ± 0.08
Sn (50)	3.41	1.040	1.043	1.024	1.05 ± 0.09
	4.76	1.491	1.500	1.470	1.43 ± 0.09
	5.97	1.858	1.874	1.833	1.81 ± 0.09
	1.81	1.271	1.281	1.245	1.25 ± 0.23
	2.65	2.285	2.317	2.245	2.33 ± 0.24
Pb (82)	3.41	3.234	3.266	3.159	3.27 ± 0.24
	4.76	4.354	4.921	4.743	4.72 ± 0.24
	5.97	6.179	6.280	6.005	6.13 ± 0.24

Table 2. Integral Rayleigh scattering cross sections of 298.6 keV gamma rays (b/atom).

Element (Z)	Angle (deg)	$(\Delta\sigma_{sca})$ Theory			$(\Delta\sigma_{sca})$ Expt.
		NRFF	RFF	MFF	
	1.81	0.019	0.019	0.019	0.016 ± 0.003
Al (13)	2.65	0.029	0.029	0.029	0.031 ± 0.004
	3.41	0.036	0.036	0.036	0.040 ± 0.004
	1.81	0.118	0.118	0.116	0.11 ± 0.02
	2.65	0.179	0.179	0.175	0.18 ± 0.02
Cu (29)	3.41	0.220	0.220	0.216	0.22 ± 0.02
	4.76	0.275	0.276	0.271	0.28 ± 0.02
	5.97	0.318	0.319	0.313	0.31 ± 0.02

Table 2. (Cont'd.)

Element (Z)	Angle (deg)	($\Delta\sigma_{sca}$) Theory NRFF	RFF	MFF	($\Delta\sigma_{sca}$) Expt.
	1.81	0.355	0.356	0.350	0.38 ± 0.07
	2.65	0.564	0.567	0.556	0.55 ± 0.08
Sn (60)	3.41	0.734	0.739	0.724	0.71 ± 0.03
	4.76	1.007	1.017	0.993	1.00 ± 0.08
	5.97	1.219	1.234	1 202	1.20 ± 0.08
	1.81	1.071	1.079	1.045	1.02 ± 0.17
	2.65	1.787	1.807	1.746	1.80 ± 0.17
Pb (82)	3.41	2.403	2.437	2.348	2.37 ± 0.18
	4.76	3 365	3.427	3.283	3.23 ± 0.18
	5.97	4.058	4.145	3.953	4.04 ± 0.18

There are no similar experimental studies measuring the IRSCS of γ-rays available in literature for comparison except the work of Bel'skii and Starodubtsev [12] which is outdated. In the case of Al, the angle have been restricted to about 4° due to the large scatterer thickness.

In the Figures 1 and 2, the experimental and theoretical IRSCS have been plotted against the scattering angle θ, for the elements and the photon energies studied. The solid

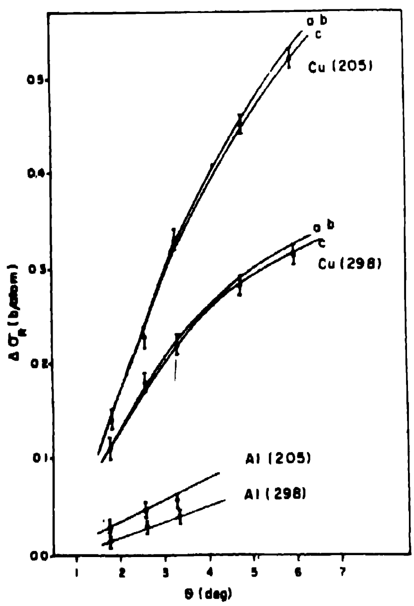

Figure 1. Comparison of the measured and the calculated IRSCS of 205.2 and 298.6 keV γ-rays for Al and Cu. Curve a – NRFF, Curve b – RFF and Curve c – MFF.

curves represent the theories whereas the circles with error bars denote the experimental values. For lighter elements (Al and Cu), there is no appreciable change among NRFF, RFF

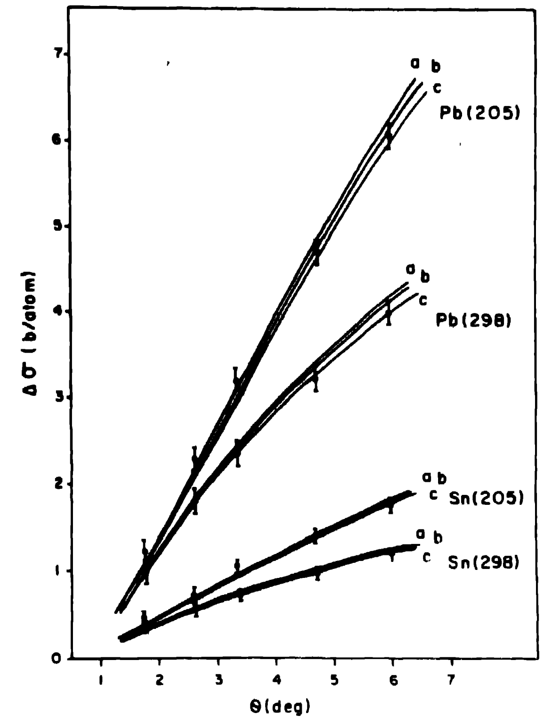

Figure 2. Comparison of the measured and the calculated IRSCS of 205.2 and 298.6 keV γ-rays for Sn and Pb. Curve a – NRFF, Curve b – RFF and Curve c – MFF.

and MFF values. As is evident from the Tables 1 and 2 and Figure 1, the experimental IRSCS for lighter elements are in good agreement with each of NRFF, RFF and MFF values throughout the angular range < 6°. However, for medium- and high-*Z* elements (Sn and Pb), as seen from Tables 1 and 2 and Figure 2, the NRFF, RFF and MFF values differ slightly such that $\Delta\sigma$(RFF) > $\Delta\sigma$ > (NRFF) > $\Delta\sigma$(MFF) and the measured IRSCS are seem to be consistently closer to the MFF values as the scattering angle increases, though there is overall agreement within the experimental errors with each of them. This is in agreement with the fact that MFF values describe the forward-angle high-energy limit Rayleigh scattering amplitude accurately above the electron threshold energies. However, RFF values are found to be definitely larger for medium- and high-*Z* elements as the scattering angle increases.

The above forward-angle cone method was expected to be more suitable at low photon energies because of larger scattering cross sections at forward angles especially for high-*Z* elements. However, it was noticed that at 145 keV, it was not at all possible to observe the scattered photons for lead though the situation improves for lighter elements. Similarly, at 661.6 keV, it was not possible to study the scattering cross sections for low-Z elements over certain energy range. The energy dependence and Z-dependence of the method has to be studied further in detail.

References

[1] G Basavaraju, P P Kane, S M Lad, L Kissel and R H Pratt *Phys. Rev.* **A51** 2608 (1995)

[2] S C Roy, B Zhou, L Kissel and R H Pratt *Indian J. Phys.* **67B** 481 (1993)

[3] P P Kane, L Kissel, R H Pratt and S C Roy *Phys. Rep.* **140** 75 (1986)

[4] L Kissel, B Zhou, S C Roy, S K Sengupta and R H Pratt *Acta Cryst.* **A51** 271 (1995)

[5] S C Roy, L Kissel and R H Pratt *Phys. Rev.* **A27** 285 (1983)

[6] P P Kane, G Basavaraju, J Mahajani and A K Priyadarsini *Nucl. Instrum. Meth.* **155** 467 (1978); *Phys. Rev* **A28** 1509 (1983)

[7] K S Puttaswany, Marigowda and B Sanjeevaiah *Nucl. Instrum. Meth.* **224** 461 (1984); *Phys. Rev.* **A30** 1311 (1984)

[8] Marigowda, S J Anasuya and K S Puttaswamy *Indian J. Phys.* **60A** 337 (1986)

[9] J H Hubbell, W J Veigele, E A Briggs, A T Brown, D T Cromer and R J Howerton *J. Phys. Chem. Ref. Data* **4** 471 (1975)

[10] J H Hubbell and I Overbo *J. Phys. Chem. Ref. Data* **8** 69 (1979)

[11] D Schaupp, M Schumacher, F Smend, P Rullhusen and J H Hubbell *J. Phys. Chem. Ref. Data* **12** 467 (1983)

[12] S A Bel'skii and S V Starodubtsev *J. Expt. Theo. Phys.* **37** 983 (1959); (English translation) *Sov. Phys JETP* **37** 700 (1960)